Forest structure in harvested sites of Afromontane forest of *Prunus africana* [Hook.f.] Kalkm., in Bioko (Equatorial Guinea)

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Abstract

Prunus africana [Hook.f.] Kalkm. has been declining over much of its geographical range during the last 40 years because of unsustainable harvesting of its bark for the international medicinal trade. In Bioko Island, bark harvesting from natural stands began in 1994, but no sylvicultural management practices have been applied. The goal of this study was to assess the impact of bark harvesting in the Bioko Afromontane forest in terms of structure, tree composition and mortality as a first step to establishing sylvicultural practices. Forty one plots were recorded on two different locations, Pico Basilé and Moka. Altitudinal distribution of *P. africana* in Bioko ranged from 1400 to 2500 m above sea level with a mean density of 7.18 stem ha^{-1}. The species *Schefflera mannii* and *P. africana* were described in the upper canopy stratum with a J-shaped diameter distribution curve. The percentage of dead trees (>30 cm DBH) was more than 10% for heavily harvested populations compared with lightly harvested areas, which presented no severe mortality. This reflects the high intensity of bark harvesting, mainly directed at large trees. Site-specific sylvicultural practices, designed considering forest structure characteristics and *P. africana* size-class distribution, must be applied to national forest policies in Bioko.

Key words: Afromontane forest, Bioko, impact of bark harvesting, nontimber forest product, *Prunus africana*

Résumé

Prunus africana [Hook.f.] Kalkm. a décliné dans la plus grande partie de son aire de répartition géographique au cours des 40 dernières années en raison de la récolte nonsoutenable de son écorce pour le commerce médicinal international. Sur l'île de Bioko, le prélèvement des écorces des plants naturels a commencé en 1994, sans que l'on applique de bonnes pratiques de gestion sylvicole. Le but de cette étude était d'évaluer l'impact de la récolte d'écorce dans la forêt afromontagnarde de Bioko, en termes de structure, de composition des arbres et de leur mortalité, pour une première étape en vue d'instaurer de bonnes pratiques de gestion sylvicole. Forty-one plots ont été suivis en deux endroits différents, Pico Basilé et Moka. La distribution altitudinale de *Prunus africana*à Bioko allait de 1400 à 2500 mètres au-dessus du niveau de la mer, avec une densité moyenne de 7,18 plants à l'hectare. Les espèces *Schefflera mannii* et *P. africana* ont été décrites dans la couche supérieure de la canopée, avec une courbe en J de distribution de diamètre. Le pourcentage d'arbres morts (>30 cm DBH) était de plus de 10% pour les populations fortement exploitées, comparées aux populations légèrement exploitées qui ne présentaient pas de mortalité sévère. Cela reflète la forte intensité de la récolte d'écorce qui touche principalement les gros arbres. De bonnes pratiques sylvicoles, spécifiques des sites et conçues en fonction des caractéristiques de la structure de la forêt et de la distribution des classes de taille de *P. africana,* doivent être appliquées à la politique forestière nationale à Bioko.

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Introduction

The forests of West Africa, including the islands of the Gulf of Guinea comprise one of the world's biodiversity hotspots (Myers, Mittermeier & Mittermeier, 2000). Bioko is the largest and closest to the mainland, only about 32 km from Cameroon. Bioko Afromontane forests are included in a tropical belt designated 'Guineo-Congolian' considering its vegetation characteristics (White, 1983). The Afromontane hardwood tree *Prunus africana* (locally called 'Pygeum') is a multiple-use species of a local and international economic and medicinal value. The bark of this species is the major source of an extract used to treat benign prostatic hyperplasia and in 1972, the commercial exploitation of *P. africana* began for international trade (Hall, O'Brien & Sinclair, 2000a). The *P. africana* geographical range has been declining because of the unsustainable harvesting of its bark, all obtained from wild populations (Cunningham & Mbenkum, 1993) and the extensive replacement of forests by other ecosystems (Hall *et al.*, 2000a).

Pygeum exploitation began in the early 20th century in South Africa and Kenya, where it was a valuable timber species. In recent decades, the pharmacological features of this plant, used to treat prostate gland hypertrophy and benign prostatic hyperplasia, have received attention on a global scale. Since the patenting of the bark extract for prostate remedy, (Cunningham & Mbenkum, 1993), it has become commercially widespread. Several practices of bark harvesting have been used (Cunningham & Mbenkum, 1993), with differing effects on the tree. As a consequence of their overexploitation, the trading of *P. africana* products has been regulated in accordance with Appendix II of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES). Based on the IUCN (2007) classification, this species has been assigned a threat category of 'vulnerable'. The *P. africana* is included in the *Database of Tree Conservation* of the World Conservation Monitoring Centre (WCMC, 1999). Furthermore, the Panel of Experts of the FAO on Forest Genetic Resources includes *P. africana* as one of the eighteen species with a maximum action priority in Africa (FAO, 1997).

In the Bioko Afromontane ecosystem, bark harvesting is the primary source of revenue. These activity and hunting practices are the only economic benefits for the local population as most *P. africana* forests are protected by Equatorial Guinea law. Preserving the biodiversity and multiple goods and services of Afromontane native forests should be one of the most important goals in global forest management. The demands upon forest NTFP (nontimber forest product) resources, with the increasing world population needs in medicinal plant treatments, are effecting pressure on the Afromontane *P. africana* forested areas (Cunningham, Cunningham & Schippmann, 1997; Dawson & Powell, 1999; Stewart, 2003). There is discrepancy between the official start of *P. africana* exploitation (WCMC-UNEP; CITES administrative authority in Spain), which affirms that bark exportation started in 1994 in Bioko Island, and that mentioned by Sunderland & Tako (1999), who suggest that it started in 1992. This pressure produces a high mortality among *P. africana* individuals (Sunderland & Tako, 1999), as a result of inappropriate harvesting techniques. National sylvicultural policies are mainly based on Mount Cameroon experiments (Cunningham *et al.*, 1997; ONADEF, 1997; Marcelin, Ndam & Bell, 2000), but no specific work on Bioko Afromontane forest management with respect to its structure and tree flora composition has yet been developed.

The density and size distribution of trees contribute to the structural pattern characterization of a forest, which has become an important factor in the analysis and management of forest ecosystems (Zenner & Hibbs, 2000). In the case of Bioko island, vegetation studies have been focused on flora identification (Nosti, 1947; Guinea, 1949, 1951; Exell, 1952; Ocaña, 1960; Fa & Juste, 1994; Jones, 1994), but there are no published results on forest structure and tree species composition of Afromontane forests on Bioko.

The principal goal of this work was to present a forest composition assessment of Bioko Afromontane forests in terms of structure, tree composition and dominance between arboreal species in harvested areas, with *P. africana* as a focus species. For that purpose, two specific objectives were developed: (i) classification of Afromontane forest areas with presence of *P. africana* based on altitudinal and site criteria and (ii) assessment of the impact of bark harvesting on *P. africana* population structure.

Materials and methods

Study area

The two study areas were located on the Island of Bioko (8°30′–8°55′N/3°15′–3°45′E), in Equatorial Guinea, Gulf of Guinea, Africa (Fig. 1). Bioko's climate is typically oceanic and equatorial, with average temperatures of 25°C in

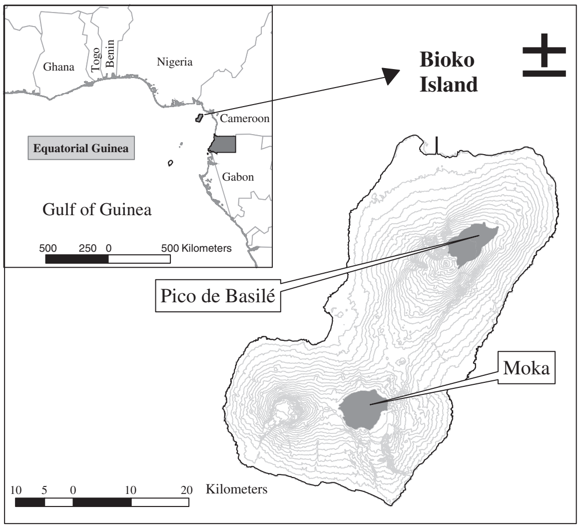

Fig 1 Location of the study area

the lowlands and monsoon influence in its southern part. Average annual precipitation is over 11,000 mm in southern Bioko, and <2000 mm in the north (Terán, 1962). Bioko has three types of soils: lithosols, eutric nitosols and ochric andosols (FAO, 2000).

Field data were acquired within the *P. africana* altitude distribution range in Bioko Afromontane forests, which varies from 1200 to 2500 m. (Sunderland & Tako, 1999), within the areas of Pico de Basilé (1.5 km away from Pico de Basilé road axis) and Moka bark harvesting zones. A digital elevation model (DEM) of Bioko (90*90 m) was used to select the study areas. The area has a tropical humid climate with a mean annual precipitation of 1916 mm and about one half of the annual precipitation occurs during the wet season (March–November). Mean temperature ranges from 25.5°C (March) to 23.8°C (August) and the atmospheric humidity is over 90% most of the year. Bioko soils are typified as *braunlehm* soils, quite rich in iron hydroxides and organic matter and with low contents of phosphorous, potassium and calcium (FAO, 2000). According to White (1983), the vegetation in the study region is Afromontane forest.

Study species

Prunus africana belongs to the subfamily Prunoideae within the Rosaceae family. There are around 200 species in the genus *Prunus*, divided into two subgenera: *Padus* (deciduous) and *Laurocerasus* (evergreen). The *Laurocerasus* subgenus includes *P. africana* as the only one found in Africa and Madagascar. The tree reaches an average height of 25 m and diameters of 0.9–1 m, (branching at 20 m), with a straight, cylindrical trunk, and often has four 8- to 10-cm-thick buttresses at the base. Leaves are alternate, simple, and elliptic to oblong, sometimes slightly ovate, 3–6 cm wide and 5–15 cm long. Flowers are small, white, fragrant, and solitary or in 3- to 7-cm-long racemes and the fruit is a drupe, 10 mm in diameter (Hall, O'Brien & Munjuga, 2000b; Hall *et al.*, 2000a,b).

Pygeum can boast of pan-African distribution, having been cited in 22 countries, mostly in the eastern part of the continent. Its altitude range falls between 600 and 3500 m, but elevations as low as 60 m have been reported. Inversely proportional to latitude, it occurs from 1000 to 3500 m in regions near the equator, whereas in South Africa, it can be found from 600 to 1000 m. It grows in forests where annual rainfall exceeds 900 mm, generally between 1100 and 1500 mm. (Hall *et al.*, 2000b; Page, 2003). *Prunus africana* stands appear both in Afromontane forests and in the transition between these and lowland forests, where they are less abundant (Hall *et al.*, 2000b). It can even be the dominant species in some Afromontane forest types, lending its name to plant communities, e.g. 'Pygeum Moist Montane Forest' (White, 1983).

Data collection

Based on these criteria, two harvesting levels were established: Pico de Basilé (heavy bark harvesting) and Moka village area (light bark harvesting), and two altitude ranges, 1429–1900 m and 1900–2148 m. Field surveying to assess the effects of *P. africana* bark harvesting on population structure was conducted in 2005 at two locations: Pico Basilé and Moka where *P. africana* occurs naturally. Bark harvested in Bioko Island began in 1994 and it has been reported in two areas. First, the road to the top of Pico de Basilé (in the North), which was harvested from 1994 to 2005 with the exception of years: 1999, 2000, 2001 and 2002, when harvesting was not permitted. In this area, *P. africana* bark was heavily harvested between 1994 and 2005, where all the trees were harvested, many of them twice. Bark harvesting areas in Pico de Basilé were established following an altitudinal range and previous flora studies (Guinea, 1951; Ocaña, 1960) in the categories 1400–1900 m and 1900–2500 m, within the bark harvesting area (1.5 km away from the road axis). The second area was the surroundings of Moka village (in the South-East) in the years 1998 and 2005, where *P. africana* bark was lightly harvested in an area around Moka village (Moka) and Lake Biaó from 1998 to 2005. In this area, some trees remained unharvested and no double debarking has been observed. In Moka, the same altitudinal range distribution (from 1400 m to the top of Pico Biaó–2011 m) as Pico de Basilé was assessed based on vegetation classification (Clemente *et al.*, 2006).

To sample the total population area and to estimate the harvesting intensity, a stratified systematic inventory every 100 m following transects was developed in December 2004 and April 2005. Transects corresponded to harvesting tracks with a mean distance of 2 km. First, a forest stratification following the altitudinal range was established by a separation between low Afromontane forest (from 1200 to 1900 m.) and high Afromontane forest (from 1900 to 2200 m). These altitudinal ranges were delimited considering previous flora studies (Ocaña, 1960) and remote sensing vegetation maps (Clemente *et al.*, 2006). Forty-one systematic plots were established, nineteen in Pico de Basilé and 21 in Moka, of 1256.6 m^2 (radius = 20 m) and the central coordinates of each plot were determined with GPS (Magellan Meridian Colour). The error accepted for GPS measurements under canopy was limited to an EPE (Estimated Position Error) < 15 m.

The number of all tree species in each plot with diameters at breast height DBH >10 cm was recorded. For *P. africana, c*anopy position (upper canopy, lower canopy) and canopy cover (visual estimation in a percentage), health (according to Sunderland & Tako, 1999), harvesting status (harvested and/or not harvested), bark thickness (SUUNTO bark gauge), number of years after bark harvesting (estimated by a field worker) and height were measured. In this study, no estimations of tree species with DBH < 10 cm assessment were made and therefore regeneration (seedlings and samplings) was not studied.

Forest structural analysis

Density was calculated as the number of trees per hectare in each of the 41 plots inventoried and canopy cover as the percent of a fixed area covered by the crown of an individual plant species or delimited by the vertical projection of its outermost perimeter; small openings in the crown are included. The basal area was calculated as the cross section area of the trunk measured at breast height of all tree individuals inventoried, expressed as square meters per hectare.

Forests can be stratified into vegetation layers of different heights and species occupying different canopy levels at maturity. Plants with a similar structure and life-form can be grouped into categories called synusiae, which make up different layers of vegetation. In tropical rainforests, the synusiae are more numerous than in other forest types (Richards, 1981). Thus, it is possible to distinguish different tree species groups such as emergent, upper canopy, lower canopy and understorey tree species as well as shrub and grass layers (Richards, 1981; Hitimana, Legilisho & Thairu Njunge, 2004). In this study, no estimations of tree species with DBH < 10 cm assessment were made and therefore regeneration (seedlings and samplings) was not studied. The importance value index (IVI) for all tree species inventoried was determined as the sum of the relative frequency (RF), relative density (RD) and relative dominance (RDo) (Curtis & Mclntosh, 1951; Cavalcante, Soares & Figueiredo, 2000). RDo was calculated as the percentage of the basal area (BA) of each species divided by the summation of the whole species BA.

Forest structure analyses based on size class distributions were performed separately for *P. africana* and for all woody species. Size classes were assigned based on 10 cm DBH increments.

Statistical analyses

Prior to analysis, descriptive statistics such as means and standard deviations of all the variables were calculated. Student's *t*-tests were performed to examine the differences between heavily and lightly harvested areas; and altitudinal range classes. Significance levels at both 0.01 and 0.05 were reported.

Results

Ecological features of Prunus africana distribution area

Table 1 presents the mean attributes of *P. africana* distribution area. Three-hundred and fifty-five individuals were recorded, representing 37 different arboreal species, but only 21 were identified (Table 2). The largest family represented in the studied area was *Rubiaceae*, with six different species inventoried. *Schefflera mannii* (Hook.f.) Harms was the most abundant species within the study area (Pico de Basilé and Moka), followed by *P. africana, Neoboutonia macrocalyx* Pax, *Nuxia congesta* R. Br. and *Ficus* sp.

Table 1 Altitudinal range, total tree density, *Prunus africana* density, total tree canopy cover, *P. africana* canopy cover and stand mean height data of pooled attributes of 37 recorded plots in the systematic inventory of Afromontane forest with the presence of *P. africana* in Bioko Island

Area of study	No. plots	Altitudinal range (m)	Tree density (stem ha^{-1})	Density of *P. africana* (stem ha^{-1})	Canopy cover (%)	*Prunus africana* canopy cover (%)	Stand mean height (m)
Systematic forest inventory							
Bioko Island	41	1429–2184	68.70	7.18	77	15	24
Pico De Basilé	20	1704–2184	61.67	7.56	67	18	26
Lowland area <1900 m	12	1704–1900	87.54	3.53	76	6	22
Highland area >1900 m	8	1900–2184	61.54	10.85	64	32	29
Moka	21	1429–1997	75.79	6.82	88	12	23
Lake Biaó	11	1833–1997	54.91	6.51	78	13	23
Biaó summit	4	1723–1829	103.45	5.31	96	8	24
Moka village	6	1429–1556	79.58	9.95	100	19	21

Table 2 Family, density (*D*) and basal area (B_a) of the principal tree species associated with *Prunus africana* species (included) in the 41 plots inventoried in Pico de Basilé and Moka

Species[a]	Family	*D* (stem ha^{-1})	B_a (m^2 ha^{-1})	RD[b] (%)	RDo[b] (%)	RF[b] (%)	IVI[b]
Prunus africana	Rosaceae	7.18	3.03	10.45	17.81	41.46	69.73
Schefflera mannii	Araliaceae	8.93	4.07	12.99	23.95	36.59	73.52
Ficus sp.	Moraceae	2.72	0.44	3.95	2.61	12.20	18.76
Nuxia congesta	Buddlejaceae	6.02	1.07	8.76	6.27	24.39	39.42
Crassocephalum mannii (Hook.f.) Milne-Redh	Asteraceae	0.39	0.01	0.56	0.07	2.44	3.08
Hypericum lanceolatum	Guttiferae	0.39	0.01	0.56	0.07	2.44	3.08
Uragoga sp.	Rubiaceae	0.39	0.25	0.56	1.45	4.88	6.89
Macaranga spinosa Müll.Arg.	Euphorbiaceae	0.58	0.19	0.85	1.09	7.32	9.25
Trema orientalis	Ulmaceae	1.36	0.35	1.98	2.07	9.76	13.80
Ficus sp.	Moraceae	0.39	0.15	0.56	0.91	2.44	3.91
Neuboutonia macrocalyx	Euphorbiaceae	3.88	0.83	5.65	4.85	12.20	22.70
Polyscias fulva	Araliaceae	0.39	0.41	0.56	2.43	4.88	7.87
Xymalos monospora (Harv.) Baill.	Monimiaceae	1.16	0.26	1.69	1.56	4.88	8.13
Psychotria sp.	Rubiaceae	0.19	0.01	0.28	0.04	2.44	2.76
Zanthoxylum sp.	Rutaceae	0.39	0.04	0.56	0.22	2.44	3.22
Psychotria peduncularis (Salisb.) Steyerm.	Rubiaceae	0.78	0.07	1.13	0.43	2.44	4.00
Psychotria sp.	Rubiaceae	0.19	0.01	0.28	0.04	2.44	2.76
Afrardisia oligantha Glig & G.Schellenb.	Myrsinaceae	0.58	0.04	0.85	0.25	2.44	3.54
Ficus chlamydocarpa subsp. *chlamydocarpa*	Moraceae	1.55	0.31	2.26	1.81	17.07	21.15
Oxyanthus sp.	Rubiaceae	1.55	0.05	2.26	0.29	7.32	9.86
Oxyanthus subpunctatus	Rubiaceae	1.94	0.06	2.82	0.36	7.32	10.50

IVI, importance value index; RF, relative frequency; RD, relative density; RDo, relative dominance.
[a]Only the species identified at genus level are shown.
[b]Calculated using all trees inventoried (N = 355) in the 41 plots.

Importance value index shows that *Schefflera mannii* and *P. africana* (IVI > 50%) species were the most dominant (RDo = 23.95 and 17.81) within the study area of Afromontane forest of Pico de Basilé and Moka, followed in overall importance (10% < IVI < 50%) by *Nuxia congesta*, *Neoboutonia macrocalyx*, *Ficus chlamydocarpa* Mulder. & Burret, *Ficus* sp., *Trema orientalis* (L.) Blume and *Oxyanthus subpunctatus* (Hiern) Keay (Table 2). The tallest trees, reaching over 40 m, were mainly not only *P. africana* and *Schefflera mannii* individuals, but also some individuals from the *Moraceae* family. Within the 41 plots, the species *P. africana* (33 individuals) and *Schefflera mannii* (39 individuals) occupied the upper canopy stratum. In areas affected by natural disturbance (forest fires), the principal species was mainly *Hypericum lanceolatum* Lam., followed in second place by *Polyscias fulva* (Hiern) Harms. The understorey was integrated by many species belonging to the *Rubiaceae* (*Uragoga* L. sp., *Oxyanthus* DC sp., *Psychotria* L sp.) and the herbaceous stratum mainly by *Anchomanes difformis* Engl., *Piper guineense* Schumach. & Thonn. and *Aframomum* K.Schum. sp.

Simplified size-class distribution using three categories was developed for the species in the upper canopy stratum: *P. africana* and *Schefflera mannii* and for two species representing the lower canopy stratum: *Neoboutonia macrocalyx*, *Nuxia congesta* (Fig. 2). Figure 2a shows DBH size-class distribution for the species in the lower canopy stratum: *Neoboutonia macrocalyx* and *Nuxia congesta*. The graphic indicated for both species the presence of a large number of individuals in the first DBH size-class category (10–30 cm) that decreases in the following categories. The opposite tendency is presented in Fig. 2b, which represents the species in the upper canopy stratum.

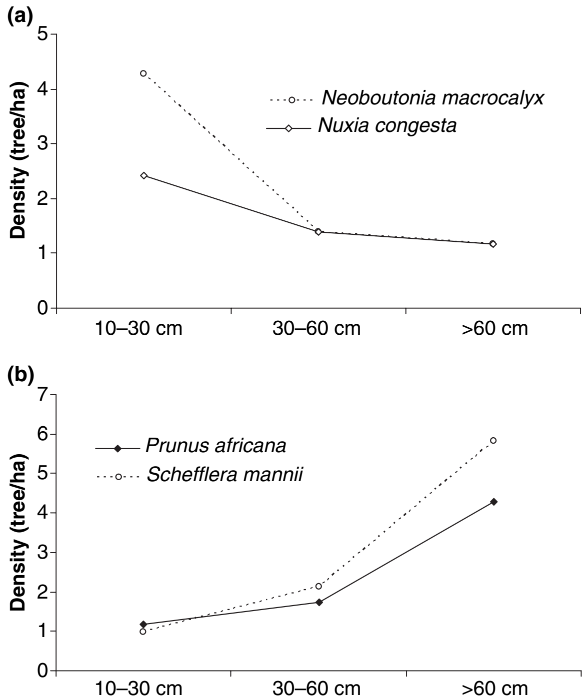

Fig 2 Distribution of tree species in Afromontane forests in Bioko (Equatorial Guinea)

Prunus africana abundance and canopy cover

The abundance and canopy cover exhibited by *P. africana* under both light and heavy levels of bark harvesting are shown in Table 3. No significant differences were found according to harvesting intensity, but altitudinal distribution was positively related to density and cover of *P. africana* (Table 3). The size-class distribution exhibited by *P. africana* under both light and heavy levels of bark extraction is shown in Fig. 3. The distribution of individuals shows different regeneration curve shapes according to harvesting intensity. The light harvesting area shows a reverse J-shaped curve, suggesting good recruitment. On the contrary, in heavily exploited populations, the density of small trees is smaller and size-classes >50 cm DBH are poorly represented with only 16% of trees, whereas this is 85% of trees in the lightly exploited sites.

Table 3 Two-way ANOVA results for heavily harvested and lightly harvested bark areas: Moka/Pico de Basilé*Prunus africana* harvesting areas; and altitude with *Prunus africana* density and canopy cover factors

Factors	N	Mean abundance of *Prunus africana* (stam ha^{-1})	*F*-value	*P*-value between groups	Mean canopy of *Prunus africana* (%)	*F*-value	*P*-value between groups
Heavily harvested	20	7.55a	0.519	0.757	17.68a	0.056	0.285
Lightly harvested	21	6.82a			12.19a		
Highland area	26	10.85a	3.224 (*)	0.019 (*)	27.09a	3.810 (*)	0.012 (*)
Lowland area	15	3.53b			4.75b		
Altitud*harvesting level			1.502	0.197		2.441	0.127

Fisher's least significant difference (LSD) groups and *P*-value between group data are presented.
(*)Denotes a statistically significant difference between mean values at the 95.0% confidence level.
Different letters indicate significant differences between treatments at $P \leq 0.05$ (ANOVA, Fisher's least significant difference groups).

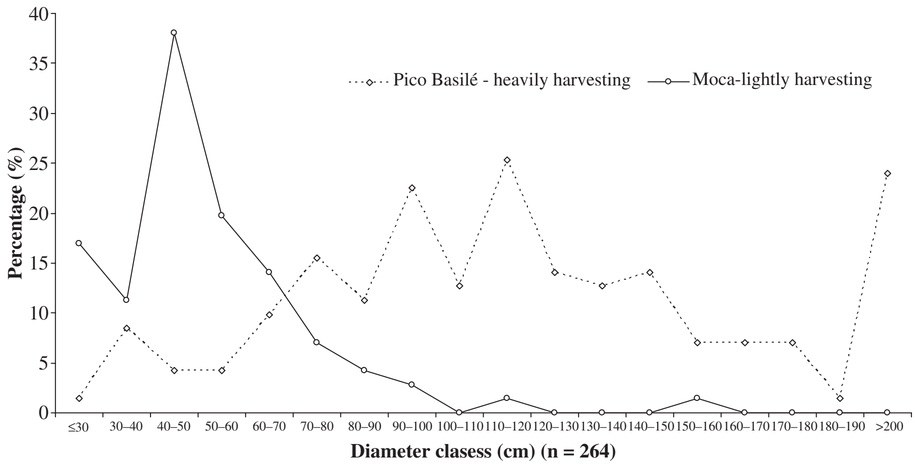

Fig 3 Comparison of the size-class distribution of *Prunus africana* populations under two harvest regimes (n = 96 individuals for lightly exploited populations, n = 168 individuals for heavily exploited populations)

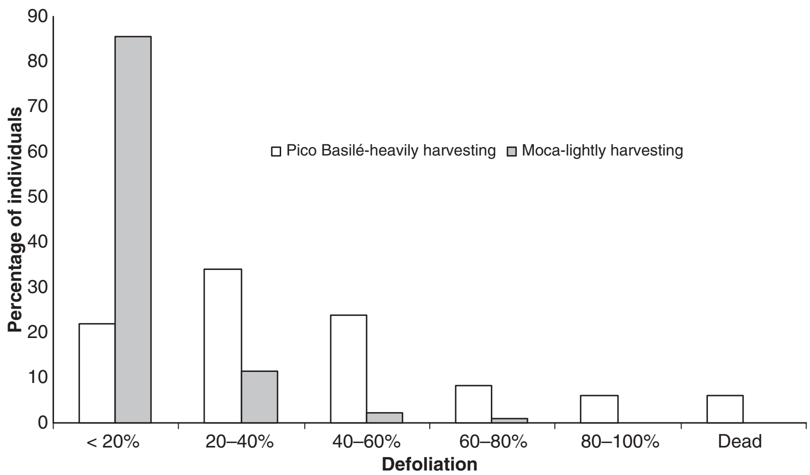

Fig 4 Comparison of the current tree mortality (no. stems > 30 cm DBH) of *Prunus africana* under two harvest regimes (n = 168 individuals for heavily exploited populations, n = 96 individual for lightly exploited populations)

With respect to harvesting, it is also interesting to consider the proportion of dead trees in each location (Fig. 4). There were evident differences between heavily and lightly exploited populations in the proportion of dead harvested trees. In lightly harvested populations, the percentage of healthy individuals surpassed 85%, while these represented only one-fifth of the entire population in heavily exploited stands. Defoliation classes above 40% represent more than 50% of the total trees in the heavily harvested areas.

Discussion

Throughout this paper, a first approach to the impact of bark harvesting of *P. africana* in Bioko has been evaluated. Population structure and the sustainability of the current harvest practices of *P. africana* bark were studied.

Afromontane forest formation of Bioko Island is commonly referred to as Araliacea Forest (Guinea, 1951; Ocaña, 1960) because of the presence of *Schefflera mannii* and *Polyscias fulva*. *Prunus africana* species had not been mentioned in those previous studies and the present results indicate that this species plays a leading role in this forest community. The importance of *P. africana* is strongly related to its BA and its RF, the highest within the tree species. *Schefflera mannii* and *P. africana* (7.18 and 8.93 stems ha^{-1}) density is quite similar, but *Schefflera* sp. density is higher, making this species the most relevant one in this Afromontane ecosystem.

Within the Afromontane forest of Bioko Island community, *P. africana* exhibits a DBH size-class distribution indicative of an established pioneer successional community and long-living species, which is characterized by a reverse j-shaped size class distribution pattern with fewer small trees, and a markedly greater number of larger diameter trees (light temperament species) (Cunningham & Mbenkum, 1993). *Prunus africana* dbh distribution in Bioko Island emphasized the low number of individuals with values of under 30 cm (a size from which no bark harvesting is permitted). The reason for this lack of young individuals can be justified in several ways. First, the recruitment problems related to the species temperament (Hall *et al.*, 2000a,b), which could account for the absence of individuals of a lesser diameter (within the 10–20 cm class). Moreover, it is assumed that the relevance of this species (except the primary forest inside the Biaó crater) has probably somewhat increased during the 1940s–1960s as the result of a disturbance, mainly livestock management, which opened it up to local population needs (Nosti, 1947) As co-dominant, *P. africana* displays a size class distribution indicative of a pioneer successional species (Hall *et al.*, 2000b). However, high mortality because of unsustainable harvesting (Sunderland & Tako, 1999) must be considered as being the major reason for the loss of middle and large diameter classes. It is to be expected that if the unsustainable bark harvesting continues, the number of *P. africana* trees will diminish.

Prunus africana and *Schefflera mannii* individuals with DHB < 30 cm were poorly represented, but the following diametric classes (30 cm < DHB < 60 cm and DBH > 60 cm) exhibited a greater abundance. This is a typical J-shaped distribution of nonshade-tolerant trees (Hall *et al.*, 2000a,b). On the other hand, a reverse J distribution for the dominant *Nuxia congesta* and *Neoboutonia macrocalyx* suggests that these secondary species are likely to continue to co-dominate this community, with relatively the same proportions in the future. The presence of a dense canopy of nondominant species (except for species of the Moraceae family) suggests that *P. africana* regeneration could be restricted in the absence of other disturbances, which open up large gaps establishing emergent specimens.

Prunus africana information indicates that the abundance of this species varies among distribution areas (Table 4). Differences in the density of *P. africana* are observed when comparing the present results with other inventories throughout the African continent, from <1 stem ha^{-1} in Cameroon and Uganda to 8 trees ha^{-1} in Ethiopia (Chapman *et al.*, 1997; Hall *et al.*, 2000a). Higher coincidences were found with Ethiopian *P. africana* density, with large differences between the inventories in Mount Cameroon standing out.

In developing countries, where most of the last primary forests still remain, environmental policies usually focus first on economic demands, neglecting forest ecosystem preservation. One solution to this problem proposed consists of the integration into economic objectives of NTFP management with the conservation of natural resources (Salafsky, Dugelby & Terborgh, 1993) and, for that

Table 4 Mean density of *Prunus africana* (stem ha^{-1}) in African

Area of study	Distribution area	Abundance (trees ha^{-1})	Reference
Bioko Island	1400–2500 m	7.18	Present study
Mount Cameroon	1500–2500 m	5.5	Eben, Ewusi & Asanga, 1992
Mount Cameroon	Dense forest with agriculture	0.87	ONADEF, 1997
Mount Cameroon	Montane and submontane forest	0.76	Ondigui, 2001
Mount Cameroon	Montane and submontane forest	0.66	Ondigui, 2001
Mount Cameroon	Agricultural	1.03	ONADEF, 1997
Mount Cameroon	Dense forest	1.17	ONADEF, 1997
Kibale National Park (Uganda)	Transition between lowland rain forest and montane forest	0.4	Chapman *et al.*, 1997
Ethiopia	Rainy Afromontane forest	7.2	Chaffey, 1980
Ethiopia	Afromontane forest	8	Chaffey, 1980

purpose, it would be necessary to optimize the efficiency of NTFP harvesting techniques and to minimize the ecological degradation caused by them. To manage NTFP tree species like *P. africana* effectively, it is vital for us to understand the impact of management practices and ecological and sociological tree behaviour and distribution.

Although not a 'reverse J' distribution, it appears likely that *P. africana* will remain a dominant species within this Afromontane forest community, sharing the upper canopy stratum with *Schefflera* sp. No statistical differences between harvesting level and unharvested areas of bark harvesting in *P. africana* density and canopy cover were detected. However, there are probably no statistical differences in forest structure between light and heavy harvesting because of the short harvesting period (<20 years), and the progressive mortality of Pygeum trees.

On the other hand, there is evidence of density decline following bark harvesting between heavily and lightly harvested areas because of crown die-back, which may increase in some heavily harvested areas because of double (even threefold) bark extraction. In this study, no differences have been found in canopy cover percentages between different levels of exploitation. Although a lower percentage of dead trees have been observed than shown before (Sunderland & Tako, 1999), the mortality of *P. africana* remains very high and an increasing number of dead trees are to be expected in the near future. In the previous work, the mortality values observed were much higher (>20%), although the number of trees evaluated in Pico Basile by Sunderland & Tako (1999) was only nineteen individuals, which could have given rise to an overestimation of the mortality in this area. It might also be thought that the dead trees found by these authors had been felled, but no stumps were found in the field, and the difficulty of gaining access to the area would not seem to have permitted this extraction. However, the data shown in this current work indicate a high mortality potential, as up to 60% defoliation classes may have died in a short period of time, which would signify an important increase in the individuals dying in the extraction areas, more apparent in the heavily harvested areas (>20%) compared with lightly harvested areas (<3%). Furthermore, the loss of adult individuals will reduce *P. africana* regeneration opportunities (Stewart, 2003).

The constraints of this work have been basically imposed by the difficulty of carrying out the field work in view of the access restrictions to the study areas (for being military zones), and by the short time authorized to do it. These circumstances limited the collection of any additional information, such as the regeneration of *P. africana*, the study of a larger region including other areas (also limited by the difficulty of moving around inside the forest), and longer temporal studies permitting the making of more complete models of the population dynamics (like that set up by Stewart, 2003).

Conclusions

Site-specific sylvicultural practices, designed considering forest structure characteristics and *P. africana* size-class distribution, must be applied to national forest policies in Bioko. Prior information would enable the fitting of extraction quotas to sustainable values, permitting the recovery of the populations. Otherwise, the forest bark revenues will suffer from negative consequences, and this valuable resource will not be profitable in the future. Sustainable exploitation of *P. africana* forests (i.e. ecologically sound and economically viable) is limited by the bark extraction from the stock of large trees. Mortality values observed after the first harvesting make a major increase in dead trees in future years predictable, which might reduce recruitment of new harvestable trees. Current intensive exploitation with harvesting practices such as ring-barking will reduce populations, which would not fully recover even after many years. However, the *P. africana* species shows a great planting facility, suggesting good characteristics as a potential crop for agroforestry (Cunningham & Mbenkum, 1993; Sunderland & Nkefor, 1997; Hall *et al.*, 2000a), which together with the management of natural populations could probably make the long-term sustained exploitation of *P. africana* bark possible.

However, the results presented in this study show a strong negative impact on *P. africana* population structure and dynamics of current harvesting practices. Mortality after harvesting causes a severe depletion in resource availability. Moreover, extraction in new areas and lack of recruitment and establishment of new seedlings might lead to the commercial extinction of the species in Bioko. Matrix models appear to be a good alternative to describe the impacts of bark extraction in *P. africana* (Stewart, 2003) and other bark-harvested-species (Guedje *et al.*, 2007) and they have been useful for modelling the effects of bark in natural populations under commercial harvesting.

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